Airborne measurements and emission estimates of greenhouse gases and other trace constituents from the 2013 California Yosemite Rim wildfire

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Introduction

- Airborne measurements of trace constituents including greenhouse gases (such as CO_2, CH_4, O_3) and biomass burning tracers (such as CO, CH_3CN) downwind of the Rim wildfire in summer 2013.
- The Rim wildfire plume was sampled by flights by the NASA Ames Alpha Jet Atmospheric eXperiment (AJAX) and NASA DC-8, as part of SEAC⁴RS.
- Emission ratios (ER), emission factors (EF) and combustion efficiency are calculated and compared with previous wildfire studies.
- Given the magnitude of the Rim wildfire, the impacts it had on regional air quality and the limited sampling of wildfire emissions in the western United States to date, this study provides a valuable dataset to support forestry and regional air quality management.

Airborne Measurements

1. Alpha Jet Atmospheric eXperiment (AJAX)

- Two AJAX flights sampling in-situ CO_2, CH_4 and O_3 and meteorological parameters on 29 August (Rim wildfire intense burning phase) and 10 September (Rim wildfire smoldering burning phase).

2. NASA DC-8 during SEAC⁴RS

- Rim wildfire emission plume was sampled on 2 consecutive days, 26 and 27 August. The DC-8 is equipped with 28 in-situ and remote sensing instruments to measure greenhouse gases, O_3 precursors and oxidation products, reactive nitrogen, and aerosol composition and physical/optical properties, and several unique tracers of pollution with high sensitivity.

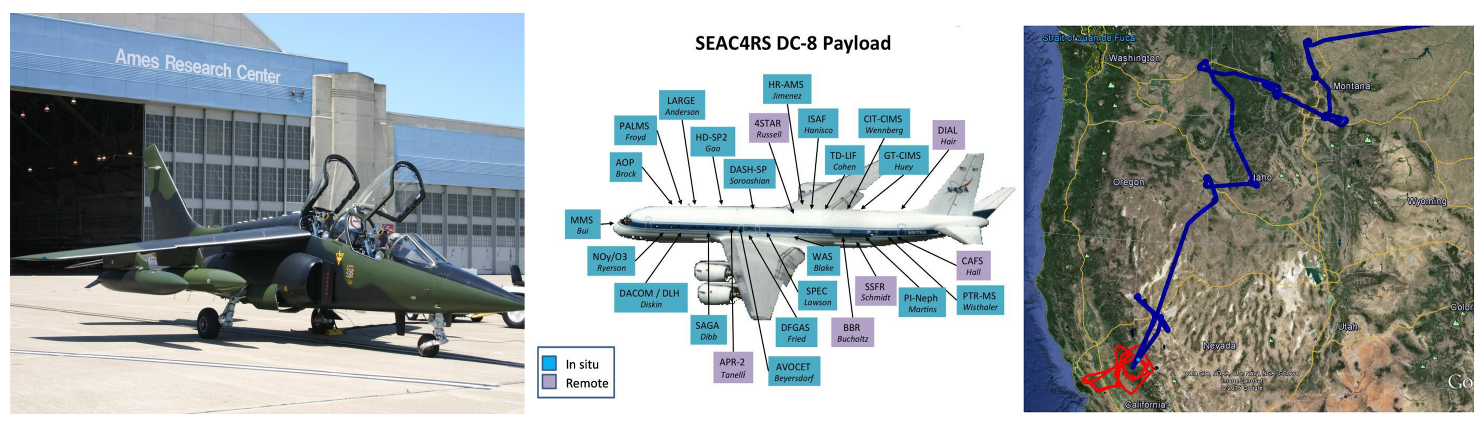

Figure 1: AJAX Alpha Jet, CO_2, CH_4 (Picarro). O_3 (2B Tech.) and MMS mounted in front section of the right, inboard wing-pod (left), instrumentation onboard the DC-8 during SEAC⁴RS (middle), airborne measurements of Rim wildfire plume, red=AJAX, blue=DC-8 (right).

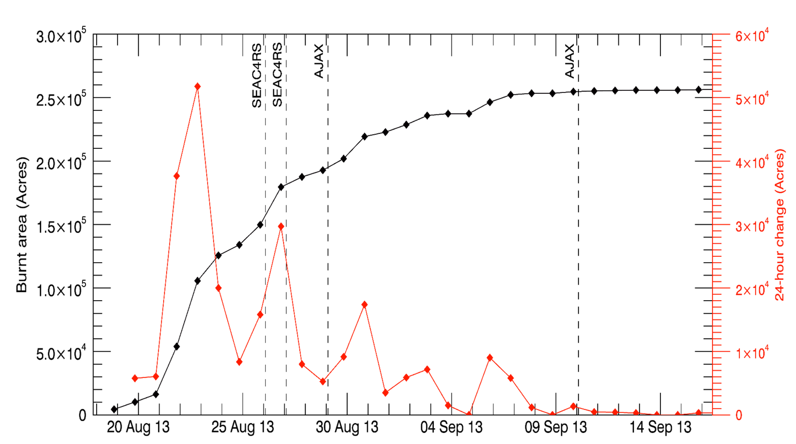

Figure 2. Timeseries of total acres burnt and 24-hour change in acres burnt based from daily fire reports (adapted from http://inciweb.nwcg.gov/incident/3660/). Timings of the AJAX and SEAC⁴RS flights are shown as the dashed lines.

References

- ***Hecobian et al., 2011***, Comparison of chemical characteristics of 495 biomass burning plumes intercepted by the NASA DC-8 aircraft during the ARCTAS/CARB-2008 field campaign. Atmos. Chem. Phys. 11, 13325-13337
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- ***Singh et al., 2010***, Pollution influences on atmospheric composition and chemistry at high northern latitudes: Boreal and California forest fire emissions. Atmospheric Environment 44, 4553-4564.
- ***Urbanski et al., 2014***, Wildland fire emissions, carbon, and climate: Emission factors. Forest Ecology and Management 317, 51-60.
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Acknowledgements:

We acknowledge the support and partnership of H211 L. L. C. for the Alpha Jet and the NASA Earth Science Program for the SEAC4RS effort. Further support was provided by San Jose State University Research Foundation, the NASA Postdoctoral Program, the Bay Area Environmental Research Institute, the National Science Foundation (AGS-1151930) and the Ames Research Center. We are thankful to SEAC⁴RS and Alpha Jet Science Teams for their contribution.

1. Intense Burning Phase

- Analysis of DC-8 flights on 26, 27 August, AJAX flight and California State University Mobile Atmospheric Profiling System (CSU-MAPS) (Clements and Oliphant, 2014), operated from Donnell Vista (119.925° W, 38.342° N, elevation 1921 m.a.s.l.).on 29 August.

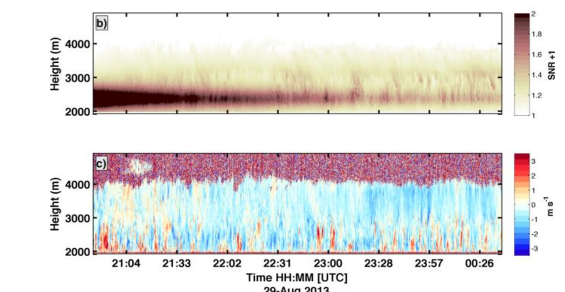


Figure 2. Lidar timeseries of signal-to-noise ratio (SNR), and vertical velocity taken at Donnell Vista on 29 August 2013.

- Three distinct layers observed by CSU-MAPS (Figure 2): The convective boundary layer (CBL, surface-3000 m) and 3000-4000 m rich in smoke from the fire plume and >4000 m the free-troposphere is devoid of emissions. The plume progressively dissipates through the course of the afternoon.

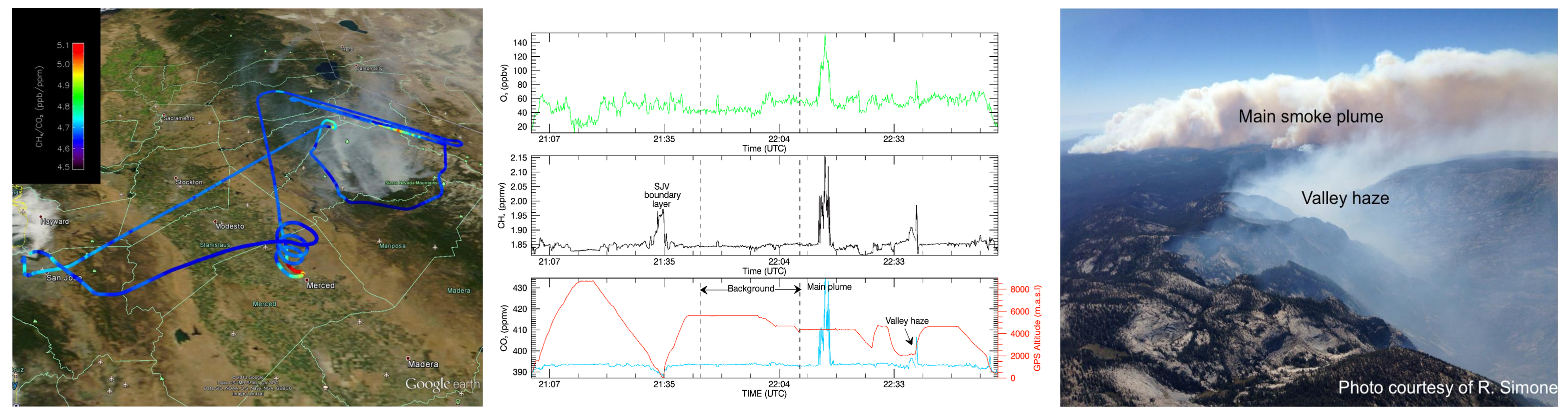


Figure 3. Map projection of CH_4/CO_2 (ppb/ppm) ratio over the 29 August 2013 flight path and location of the smoke plume as viewed by Terra/MODIS (left) timeseries of O_3 (top), CH_4 (middle) and CO_2 (bottom) from AJAX flight on 29 August (middle), photograph of the main smoke plume and low altitude smoke in Bear Valley (38.367° N, 120.170° W) on 29 August (right).

- AJAX flight show large deviations from background mixing levels of CO_2, CH_4 and O_3 within the Rim Fire plume and San Joaquin Valley (SJV) boundary layer (Figure 3, middle).
- Evidence of biospheric uptake of CO_2 and local CH_4 emissions in the SJV boundary layer.
- The average Rim wildfire enhancements ratios observed by the SEAC⁴RS flights are presented in Table 1 with $\Delta O_3/\Delta CO$ = 0.03, $\Delta PAN/\Delta CO$ = 2.6 and $\Delta NOx/\Delta CO$ = 3.8, these enhancements represent some ageing of the plume from the fit-curves shown in Figure 4.
- Both AJAX and SEAC⁴RS observations support the concept of rapid O_3 formation within the Rim wildfire plume.

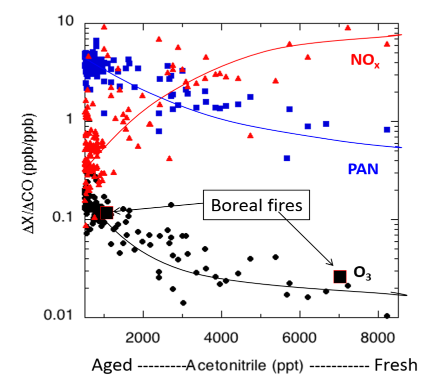


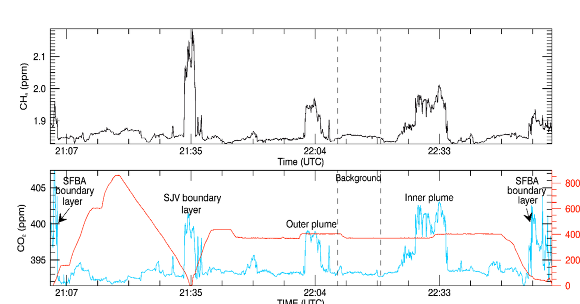
Figure 4. Evolution of key constituents in the Rim Fire plume during 0-3 day transport time, measured during SEAC⁴RS

Enhancement ratios relative to CO	Rim Fire plume 26 and 17 August 2013[a]	ARCTAS-CA California BB plumes[b]	ARCTAS Boreal biomass burning (BB) plumes: Fresh BB plumes Singh et al., 2010	ARCTAS Boreal biomass burning (BB) plumes: Simpson et al., 2011; Hecobian et al., 2011
$\Delta CH_4/\Delta CO$ (ppb/ppb)	0.08 ± 0.003	0.09 ± 0.007	0.08	0.07
$\Delta CO_2/\Delta CO$ (ppb/ppb)	9.6 ± 0.23	12.8 ± 0.8	9.4	-
$\Delta CH_3CN/\Delta CO$ (ppt/ppv)	1.3 ± 0.03	1.8 ± 0.03	2.0	1.8
$\Delta O_3/\Delta CO$ (ppb/ppb)	0.03 ± 0.001	0.1 ± 0.04	0.03	-
$\Delta NO_y/\Delta CO$ (ppt/ppb)	8.2 ± 0.3	1.6 ± 0.1	8.3	15.4
$\Delta NO_x/\Delta CO$ (ppt/ppb)	3.8 ± 0.3	2.5 ± 0.07	3.5	1.7
$\Delta PAN/\Delta CO$ (ppt/ppb)	2.6 ± 0.04	4.5 ± 0.2	2.7	-
$\Delta NO_3/\Delta CO$ (ng m^{-3}/ppb)	6.6 ± 0.6	10.4 ± 0.9	6.3	4.0
$\Delta CH_3OH/\Delta CO$ (ppt/ppb)	15.4 ± 0.3	3.2 ± 0.5	15.6	9.6
$\Delta CH_3COCH_3/\Delta CO$ (ppt/ppb)	2.9 ± 0.06	0.3 ± 0.02	4.7	1.6
$\Delta C_7H_8/\Delta CO$ (ppt/ppb)	0.9 ± 0.02	1.1 ± 0.05	0.7	0.7
$\Delta C_6H_6/\Delta CO$ (ppt/ppb)	1.6 ± 0.03	1.8 ± 0.3	1.6	1.7
$\Delta SO_4/\Delta CO$ (ng m^{-3}/ppb)	3.3 ± 0.09	4.1 ± 0.07	3.0	-
$\Delta BC/\Delta CO$ (ng m^{-3}/ppb)	2.5 ± 0.06	118 ± 2.8	1.6	-
$\Delta OA/\Delta CO$ (ng m^{-3}/ppb)	233 ± 3.2	12.8 ± 0.8	155	150

Table 1. Enhancement ratios (± 1-sigma uncertainty of the slope) relative to CO from the Rim wildfire emissions (measured on 26 and 27 August 2013) compared to enhancement ratios reported from the ARCTAS campaign (Singh et al., 2010; Simpson et al., 2011; Hecobian et al., 2011). [a] enhancement ratios from the SEAC⁴RS DC-8 study. [b]data from Californian wildfires observed during ARCTAS-CA DC-8 study calculated based on archived data (http://www-air.larc.nasa.gov/cgi-bin/ArcView/arctas).

- The combustion stage of the Rim wildfire was estimated using MCE calculated during the two SEAC⁴RS flights. During both flights on 26 and 27 August 2013 MCE was reported within the 0.9-1.0 range, representing flaming combustion.
- Table 1 provides the mean enhancement ratios for a variety of species relative to CO within the Rim wildfire plume on 26 and 27 August 2013, presenting a direct comparison with enhancement ratios from a variety of Boreal and Californian wildfires sampled during the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) campaign in spring and summer 2008

2. Smoldering Burning Phase



- The second AJAX flight was on 10 September 2013, by which time the Rim wildfire was 80 % contained and had burned 250,000 acres. Overnight easterly downslope winds brought smoke from the Rim Fire into the San Joaquin Valley (SJV). Sharp increases in CO_2 and CH_4 were observed within the SJV boundary layer and during Rim Fire (Figure 4).

3. Emission measurements

- ER's were 6.5-7.8 ppb CH_4 (ppm CO_2)$^{-1}$ during the intense burning phase. The similarity between CH_4 ER's during period between 26, 27 and 29 August 2013 is likely due to a similarity in fire conditions and fuels burnt. And suggests emissions of other species during this time would similarly agree.
- During the smoldering phase the CH_4 ER increased to an average of 16.7 ppb CH_4 (ppm CO_2)$^{-1}$, likely a result from a change in fire conditions (increase in smoldering relative to flaming combustion) and changes in fuel/materials involved.

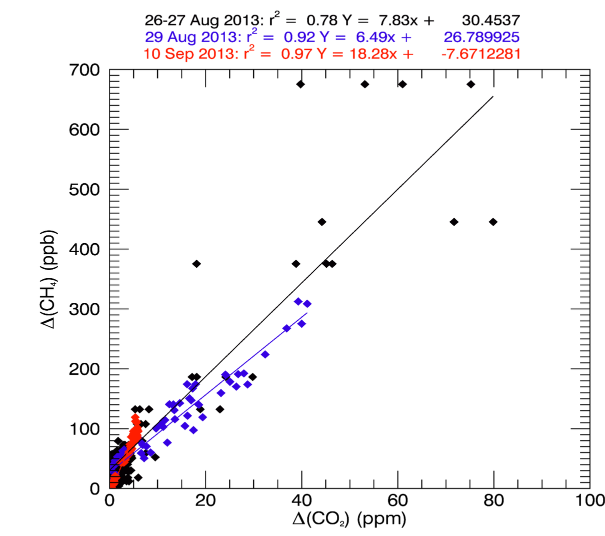


Figure 6. Relationship between CH_4 and CO_2 enhancements from the Rim wildfire plume measured during flights on 26 and 27 August (black), 29 August (blue) and 10 September (red) 2013.

$$EFx = F_c \text{ x } \frac{MM_x}{12} \text{ x } \frac{\Delta x}{\Delta C_{CO_2} + \Delta C_{CO} + \Delta C_{CH_4}}$$

Equation 1

Emission factors (g kg-1)	Rim Fire[a]: 26, 27 Aug-13	Rim Fire[a]: 29-Aug-13	Rim Fire[a]: 10-Sep-13	ARCTAS-CA California BB plumes[a]	ARCTAS Boreal biomass burning (BB) plumes: Fresh BB plumes Singh et al., 2010	ARCTAS Boreal biomass burning (BB) plumes: Simpson et al., 2011	Rocky Mountains conifer forest fires: Urbanski et al. (2013)
MCE CO	0.94[b] 92.5	0.94[c] 69.5	0.88[d] 138.4	0.90[b] 164.1	- 108.2	0.89 113	0.85 – 0.92 89.3 - 173
CO_2	1674.8	1711.2	1595.1	1571.5	1649.7	1616	1528 - 1681
CH_4	4.8	4.7	7.5	13.0	4.9	4.7	4.4 - 12.1
CH_3CN	0.14	-	-	0.31	0.32	0.30	-
HCN	0.18	-	-	0.24	0.58	0.89	-
C_3H_6O	0.56	-	-	0.85	1.05	0.37	-
CH_3OH	1.6	-	-	1.9	1.9	1.2	-
Benzene	0.40	-	-	0.63	0.48	0.55	-
Toluene	0.26	-	-	0.25	0.25	0.34	-

Table 2. Modified combustion efficiency (MCE) and emission factors (EFs) for long-lived compounds measured within the Rim wildfire plume compared to previous studies.

- EF's are typically calculated using the carbon mass balance approach (Yokelson et al., 1999) (see Equation 1).
- EF's for the Rim wildfire were calculated from the SEAC⁴RS flights on 26 and 27 August 2013 for a range of long-lived compounds (see Table 2).
- Given the similarity of ERs observed on 26, 27 and 29 August 2013, a similarity in fire conditions can be implied. We use the median MCE from SEAC⁴RS flight data to calculate EFs for CO_2 and CH_4 during the AJAX flight on 29 August 2013.
- For the AJAX flight on 10 September 2013 we use MCE of 0.88, reported by Urbanski (2014) as a typical MCE for wildfires in northwestern US conifer forests, to estimate EFs for CO_2 and CH_4 (see Table 2).

Conclusions

- This study provides a novel set of airborne wildfire ER's and EFs taken at the source, within a fresh wildfire plume at different stages of its burn cycle that will inform modeling and other studies of wildfires in the western United States.

1. Intense Burning Phase

- Lidar depicts three distinct layers; the convective boundary layer (CBL, surface-3000 m) and 3000-4000 m, rich in smoke from the fire plume and >4000 m devoid of emissions.
- Airborne measurements show large deviations from background levels within the Rim wildfire plume and within the San Joaquin Valley (SJV) boundary layer.
- Upwind of the Rim wildfire plume, evidence of biospheric uptake in SJV was observed.
- Three flights support O3 formation within the plume, MCE was reported within the 0.9-1.0 range, representing flaming combustion and enhancement ratios (ERs) relative to CO provide a direct comparison with other studies including ARCTAS.

2. Smoldering Burning Phase

- The second AJAX flight took place when the Rim wildfire was 80 % contained and had burned 250,000 acres. Overnight easterly downslope winds brought smoke from the Rim wildfire into the SJV. Sharp increases in CO_2 and CH_4 were observed within the SJV boundary layer and during Rim wildfire.

3. Emission Measurements

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- EF's for the Rim wildfire were calculated for a range of long-lived compounds and compared with previous studies.